Effect Of Fine Alum Waste Addition On The Properties Of Ordinary Portland Cement Mortar

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Abstract:- Alum waste obtained from the Aluminum Sulfate Company of Egypt (Shaba Al- Masria) causes several environmental problems related to its particles fineness. The use of this fine alum waste (particle size < 75 micron)in the preparation of cement mortar paste was studied. The effect of ninelevels of sand substitution of fine waste addition from 0 to 22.5% by weight on the properties of the formed mortars was investigated. These properties include the fluidity of mortar, the initial and final setting and the 28 days compressive strength. Also replacement of cement by waste by 5%, 10% and 15% for an addition level of 20% was studied.

Key words: Alum waste, fine particle size, consistency, initial and final setting, compressive strength.

I. INTRODUCTION

In the industrial production of alum, kaolin is calcined at temperatures higher than 500^{o}C to break down its sheet structure and form the active species metakaolin. This is then reacted with sulfuric acid to produce a solution of aluminum sulfate (alum) which is mainly used in the clarification of water. The formation of large quantities of dealuminated kaolin (Alum waste) is the cause of direct environmental threats owing to its acidic nature besides the fineness of the particles.

In this work, fine alum waste (< 75 micron) was characterized physically and chemically. The influence of substituting sand by alum waste in levels reaching 22.5% on consistency, initial and final setting of cement and compressive strength of cement mortar at 28 days was investigated.

II. PREVIOUS WORK

Egypt is among few countries producing aluminum sulfate alum for water purification from domestic kaolin (35% Al2O3). This is since bauxite, the conventional raw material for the production of alum, is not locally available [1 – 6].

On the other hand, the rheological properties of a fresh cement paste play an important role in determining the workability of concrete. The water requirement for flow, hydration behavior and properties of the hardened state largely depends upon the degree of dispersion of cement in water. Properties such as fineness, particle size distribution, and mixing intensity are important in determining the rheological properties of cement past [7]. The only work of relevance to the present study was performed by Abdel Alim et al [6] and recently by Bendary et al.[8] who found out that the flowability of OPC mortars was unaffected by adding dealuminated kaolin.

III METHODOLOGY

RAW MATERIALS

Sand:Natural sand composed was used as fine aggregate in this study. The sand was graded so as to pass from sieve 850µm and be retained on 600 µm according to ASTM C778-06 [9].

Water:Tap water was used for mixing and curing of cementfor all specimens.

Ordinary Portland cement (OPC):OPC produced by Suez Cement Company was used. Testing of cement was carried out according to the Egyptian Standard ESS4756-1/2009, where the percent retained on sieve 170 was less than 10%.Table1 shows the physical properties OPC while Table 2 illustrates the chemical composition of OPC.

TABLE 1: Physical properties of OPC

Property	Value	Limits
Specific Gravity	2.63	2.5 – 2.75
Bulk density, kg.m^{-3}	1780	-
Clay and fine dust content by volume	0.85	Not more than 3

TABLE 2: Chemical composition of OPC (% by weight)

Oxide	SiO_2	Al_2O_3	Fe2 O3	CaO	MgO	SO_3	LOI
%	21.2	5.32	3.52	63.8	1.32	2.01	2.52

Fine alum waste: Alum waste obtained from the Aluminum Sulfate Company of Egypt was first dried at 110^{o}C overnight. The dried waste is then screened to fractions.The chemical analysis of the fine fraction (under 75 micron)is shown in Table 3.

TABLE 3: Chemical Analysis of fine alum waste fraction

Constituent (wt%)	Under 75 micron
SiO_2	71.46
TiO_2	2.68
Al_2O_3	10.89
Fe2O3tot.	0.79
MgO	0.03
CaO	0.72
Na_2O	0.08
K_2O	0.06
P_2O_5	0.06
SO_3	5.25
Cl	0.03
ZrO_2	0.155
LOI	7.69
Total	99.9

On the other hand, aluminum waste was subjected to XRD analysis using a Burkur D_8 Advanced Computerized X–Ray Diffractometer apparatus to disclose its constituting phases. The results, illustrated reveal that its main crystalline phases are quartz and Anatase (TiO_2) (Fig. 1). The presence of alumina and sulfur oxide in the XRF analysis (Table 3) suggests the presence of aluminum sulfate presumably in amorphous state as no characteristic lines showed up in the XRD pattern. Stoichiometric calculations based on the XRF results have been performed. They show that most of the alumina in the waste is present as part of the unreacted metakolin and only a minor portion (about 10%) is present as aluminum sulfate. Assuming that metakaolin has the chemical symbol $Al_2O_3.2SiO_2$, this means that about 8% of the available silica present in combined metakaolin form. The percent free silica should then be about 64%. This was actually confirmed by determining the free silica present in a sample of waste by a traditional technique used for refractory materials [10].This method yielded percent free silica of 66.4%.

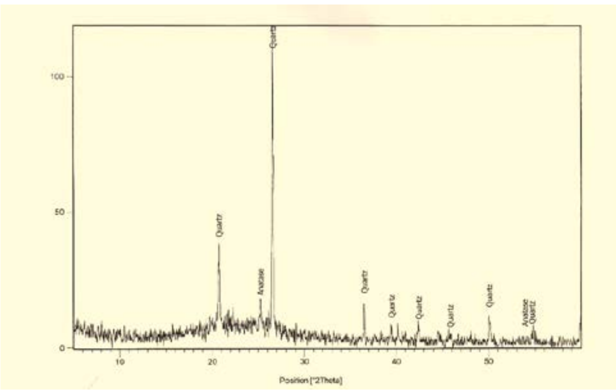

Fig. 1 XRD of alum waste

MIXING AND CURING

This was determined by the consistency test described by IS 4031-Part4 [11].Fine alum waste was used to substitute sand and was calculated as percent of cement. The waste levels were varied from as an addition of 0% to 22.5% of cement by weight as shown in Table 4. The ratio of cement to sand + waste mixture was kept at 1:2.75 by weight in all mixes.

Mixing was done in a standard drum type mixer; sand, cement and alum waste were mixed in dry state until the mixture becomes homogenous, then water was added to the dry mixture and mixing was performed for 10 minutes.

DETERMINATION OF MIX PROPERTIES

Flowability:

The test used to that aim is the flow table test performed in accordance with ASTM C230 / C230M – 14 [12].

TABLE 4: Composition of cement – waste mixes

Mix designation	OPC,g	Alum waste, g
A 0	100	0
A 2.5	100	2.5
A 5	100	5
A 7.5	100	7.5
A 10.0	100	10
A 12.5	100	12.5
A 15	100	15
A 17.5	100	17.5
A 20	100	20
A 22.5	100	22.5

In this test, a layer of mortar of about 25 mm thickness is tamped20 times in a flow mold that is placed at the center of the table. After one minute, the mold is carefully lifted and the flow table lifted up 40mm and then dropped 15 times, causing the paste to flow. The flowability is measured as the ratio between the diameter of the resulting mass and that of the original mix:

$$\text{Flowability} = \frac{D_f - D_i}{D_i} \times 100\% \qquad (1)$$

Where,

D_f = final diameter (mm)

D_i = initial diameter (mm)

Initial and final setting:

This standard test was performed as described by IS 4031-Part5 [13]. It involves using the standard Vicat needle in assessing its penetration in a fresh cement mix. Three specimens were tested each time and the average value was taken.

Compressive strength:

Compressive tests at 28 days were carried out on 70.7×70.7×70.7 mm cubes. The test specimens were immersed in water in curing tanks after 24 hours for 28 days. The test was carried out according to Egyptian standard ESS 1658-1991 [14]. Three specimens were tested each time and the average value was taken.

IV EXPERIMENTAL RESULTS

EFFECT OF FINE ALUM WASTE OF FRACTION (<75 MICRON) ON FLOW:

The results of flow test are shown in Table 5.

TABLE 5: Effect of fine alum waste on flow of hydraulic cement mortar

Alum waste (%)	Cement (g)	Waste (g)	Sand (g)	Water (g)	Flow (%)
0%	170	0.00	467.50	110.5	110
2.5%	170	4.25	463.25	110.5	108
5%	170	8.5	459	110.5	106.6
7.5%	170	12.75	454.75	110.5	95
10%	170	17	450.5	110.5	92.5

This table indicates a regular decrease in flowability of the mixes on substituting sand by waste. This is probably due to the enhancement of the reaction between the fine silica present in the waste and calcium hydroxide beginning to form owing to early hydration of alite (C_3S) producing $C_3S_2.xH_2O$ crystals. This reaction produces more alite which subsequently hydrates thus contributing to decreased flowability. This result would mean that any addition that would enhance the above reaction should lead to decreasing the flowability. Actually, this result was found to be not necessarily true in case of adding extremely fine fly ash (<10 μm) to cement [15].

EFFECT OF FINE ALUM WASTE ADDITION ON CONSISTENCY AND SETTING TIME:

The results of consistency and setting time are shown in Table 6.

TABLE 6: Effect of fine alum waste addition on consistency, initial setting and final setting of cement mortar

waste	Cement weight (g.)	Alum waste weight	W/C %	Initial setting time (min)	Final setting time
0%	300	0	29.5%	120	190
2.5%	300	7.5	30.5%	170	215
5%	300	15	32%	145	180
7.5%	300	22.5	34%	140	180
10%	300	30	35%	140	180

An increase in water of consistency is observed on increasing the percent waste addition, from 29.5% at zero addition to 35% at 10% addition. It is also to be noted that on using plain sand with no waste in the mortar, the values of initial setting times were practically at their minimum. This is presumably related to the non- porous character of sand which prevents any water from being sucked by capillary action in pores. Upon adding the waste, water is sucked in its pores by capillary action owing to its porous character causing a decrease in the effective amount of water available for hydration thus prolonging the duration of setting. However, after about 7.5% substitution, the initial and final setting times were not affected by more waste addition.

EFFECT OF ALUM WASTE ON COMPRESSIVE STRENGTH:

The effect of adding fine alum waste percentages on compressive strength of cement mortar at 28 days is shown in Table. 7. It can be seen from the results, there is a regular increase in strength following an increase in waste addition until a maximum value was reached at 17.5 – 20% substitution with an increase of 46.4% over that of the control sample (0% addition). It is believed that this level of addition is sufficient to neutralize calcium hydroxide present in the pores of the mortar to produce $C_3S_2.xH_2O$ crystals and any further addition will only act as inert filler decreasing rather than increasing the strength. These results despite being promising are not as good as those obtained on using silica fume as additive [16]. They are displayed in Fig 2.

TABLE 7: Effect of fine alum waste fraction on 28 days compressive strength

Mix design	Average Compressive strength (MPa)
A0	40.77
A 2.5	41.73

A 5	41.8
A7.5	43.27
A10	44.53
A12.5	46.53
A15	48.87
A17.5	59.17
A 20	58.37
A 22.5	51.53

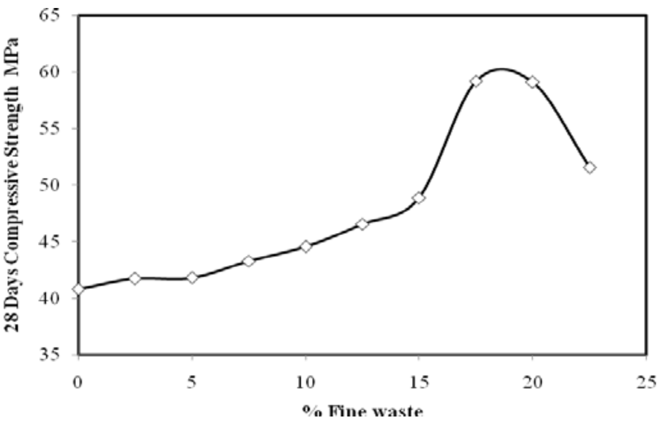

Fig. 2 Effect of substituting fine alum waste for sand on the 28 days strength

EFFECT OF PERCENTAGE REPLACEMENT OF CEMENT BY ALUM WASTE IN MIX DESIGN A20 ON COMPRESSIVE STRENGTH:

Furthermore, it was tried to substitute cement by waste for mixes where 20% substitution of sand was effected. The results are shown in Table 8 and reveal an expected drop in compressive strength following increased substitution of cement by waste. However, despite this decrease, the figure of compressive strength at 15% substitution was about 49 MPa, showing a 20% increase over the control sample. Further increasing of waste substitution for cement showed a rapid drop in strength. The aforementioned table also indicates the weights of each component in the mix.

TABLE 8: Effect of substitution of waste for cement on the 28 days strength of Mix A20 mortars

% Cement replacement	OPC,g	Alum waste,g	Sand, g	Strength MPa
0%	620	124	1581	58.37
5%	589	124+31	1581	53.93
10%	558	124+62	1581	52.03
15%	527	124+93	1581	49.03

V CONCLUSION

In this work, alum waste was used to substitute part of sand in cement mortars and subsequently to replace cement in a chosen mix. The following results were obtained.

- Initial and final setting times showed an increase in value as sand was substituted by waste presumably because of the non-porous nature of sand compared to alum waste. The setting times increased up to about 7.5% addition to stabilize on further addition.
- An addition of 17.5 to 20% waste produced an increase of 46% in the 28 days strength of cement mortars over the control values.
- Cement was substituted by waste for a mix where 20% substitution of sand has taken place. Results indicated that it was possible to substitute as much as 15% cement by waste with compressive strength values exceeding the control values by 20%
- It is not possible to use more than 7.5% sand replacement by alum waste in preparing mixes of improved strength for reinforced concrete. The potential applicability of this result has to be restricted to plain concrete because of the high sulfate content of the waste,this being restricted to 0.3% of cement weight. BS812-118 [17].

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